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# RESEARCH MEMORANDUM

EFFECT OF FUEL VOLATILITY ON PERFORMANCE OF

TAIL-PIPE BURNER

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EFFECT OF FUEL VOLATILITY ON PERFORMANCE OF TAIL-PIPE BURNER

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SUMMARY

As part of an investigation to determine the performance
possibilities of lower-volatility fuels, two fuels having Reid vapor
pressures of 6.3 and 1.0 pounds per square inch, respectively, were
investigated in a tail-pipe burner on an axial-flow turbojet engine.
A flight Mach number of 0.6 was simulated at altitudes from 20,000
feet to 45,000 feet. The first fuel was MIL-F-5624 and the other
a similar base stock with the lighter fractions removed.


With the burner configuration used in this investigation, having a
mixing length of only 8 inches between the fuel manifold and the flame
holder, the low-vapor-pressure fuel gave lower combustion efficiency at
a given tail-pipe fuel-air ratio. For operation with a fixed exhaust-
nozzle area this reduction in burner efficiency resulted in lower tem-
peratures and pressures in the tail-pipe and at the turbine outlet, with
an attendant decrease in net thrust and rise in specific fuel consump-
tion. The maximum operational altitude of the tail-pipe burner was
practically unaffected by the change in fuel volatility.

INTRODUCTION

The use of MIL-F-5624 fuel, which is the current fuel specification
for aircraft gas-turbine engines, has resulted in substantial vaporization
losses in turbojet aircraft at high altitudes because of the relatively
high fuel volatility. Even more serious fuel losses occur when liquid
fuel is entrained with the escaping vapor during rapid climb. Some of
the more obvious methods of alleviating this difficulty are by fuel-
tank pressurization, by fuel refrigeration, or by the use of lower-
volatility fuels. The first two of these methods are both cumbersome
and complicated in addition to being subject to mechanical failure and
battle damage. Thus investigations are being conducted with fuels of
lower volatility to determine whether they are suitable from the view-
point of engine performance and operating characteristics.

Previous investigations (references 1, 2, and 3) have determined
the effect of changes in fuel volatility on the performance and alti-
tude starting limits of turbojet engines. The object of the investi-
gation reported herein is to determine the effect of a change in fuel
volatility on the performance of a tail-pipe burner. The data were
obtained in an altitude test chamber at the NACA Lewis laboratory dur-
ing the latter part of 1950. A flight Mach number of 0.6 was simulated
at altitudes from 20,000 feet to 45,000 feet and the altitude limit of
operation of the burner was also determined.

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## APPARATUS AND PROCEDURE

### Fuels

The low-volatility fuel used in this investigation was of similar
base stock to the current MIL-F-5624 specification but had a Reid vapor
pressure of 1.0 pound per square inch as compared to 6.3 pounds per
square inch for the MIL-F-5624 fuel with which its performance is
compared. Assuming a constant fuel temperature of 70° F, this reduction
in vapor pressure increases the altitude at which 3 percent of the fuel
may be lost by equilibrium vaporization from 40,000 feet to 75,000 feet.
Analyses of the two fuels are given in table I.

The fuel supply to the engine combustors was MIL-F-5624 regardless
of which fuel was being used in the tail-pipe burner.

### Power Plant

The engine used in this investigation was an axial-flow turbojet
engine having a static sea-level thrust rating of 5100 pounds. It was
provided with a tail-pipe burner consisting of a fuel manifold, a V-
gutter flame holder, and a two-position clamshell-type exhaust nozzle.
A schematic cross-sectional view of the engine, showing instrumentation
stations, is presented in figure 1 and more detailed sketches of the
fuel manifold and flame holder are shown in figure 2. The fuel manifold
was mounted in the turbine-exhaust cone and consisted of two concentric
rings of tubing connected by 12 spray bars. Each spray bar contained two
rows of fuel orifices, which injected the fuel at an angle of 45° to the
upstream direction. The flame holder consisted of two annular gutters
of NACA design and was mounted in the tail pipe about 8 inches downstream
of the fuel manifold. The exhaust nozzle was automatically controlled
to open on ignition of the tail-pipe burner.

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## Instrumentation

Thermocouples and total-pressure tubes spaced around the compressor inlet were used for setting the simulated engine-inlet conditions. Static-pressure taps were provided in the wall of the inlet annulus so that this same instrumentation could be used for the measurement of air flow. A complete survey of temperatures and total pressures was made in the exhaust cone just downstream of the turbine and a water-cooled total-pressure rake was mounted downstream of the flame holder at the entrance to the exhaust nozzle. The exhaust altitude pressure was indicated by a lip static-pressure tap on the cooling shroud surrounding the exhaust nozzle. Engine and tail-pipe-burner fuel flows were measured by calibrated rotameters.

## Altitude Test Chamber

The engine was mounted in a 10-foot-diameter altitude test chamber shown schematically in figure 3. The inlet and exhaust sections of the chamber are separated by the front bulkhead and valves are provided for controlling the pressures in each section. An inlet cowling mounted on the engine incorporates a low-friction labyrinth seal, which passes through the bulkhead so that the engine is surrounded by the altitude pressure. The tail pipe passes through a clearance hole in the rear bulkhead, the purpose of which is to prevent the circulation of large quantities of hot gases in the engine compartment. Exhaust gases are collected by a diffuser and are carried through dry-type coolers with water sprays operated when necessary. Engine thrust is measured by a null-type balanced-pressure-diaphragm thrust cell connected to the engine platform by a linkage under the chamber.

## Procedure

Data were obtained for each fuel over the full range of tail-pipe-burner operation (from lean fuel-air ratio blow-out of the burner to the limiting turbine-discharge temperature of the engine) at rated engine speed. The engine speed was held constant for all data even though this may have caused variations in the inlet conditions to the tail-pipe burner. At a simulated flight Mach number of 0.6, altitudes of 20,000, 30,000, 40,000 and 45,000 feet were investigated and the altitude limit of operation of the tail-pipe burner was determined for the same simulated flight Mach number over a range of burner fuel-air ratios.

## RESULTS AND DISCUSSION

The performance of the tail-pipe burner using 1.0-pound Reid vapor-pressure fuel is compared with the performance using 6.3-pound vapor-pressure fuel (MIL-F-5624) for a flight Mach number of 0.6 at altitudes from 20,000 feet to 45,000 feet.

The principal effect of the change in fuel volatility was a loss in combustion efficiency of the tail-pipe burner at a given tail-pipe fuel-air ratio (fig. 4) and all other performance differences between the two fuels are a direct result of this loss in efficiency. The peak efficiency with the low-vapor-pressure fuel also occurred at a higher fuel-air ratio. The discrepancy in this trend of the data for an altitude of 20,000 feet is due to a difference in the engine-inlet temperature setting between the two curves. The engine-inlet temperature for the low-vapor-pressure-fuel curve was about 20° F higher than that for the MIL-F-5624 fuel curve resulting in a lower corrected engine speed; therefore, the data are not directly comparable to the other curves. The tail-pipe fuel-air ratio is defined as the ratio of tail-pipe burner fuel flow to unburned air in the turbine-exhaust gases entering the burner.

It is believed that the drop in combustion efficiency is largely due to the fact that the 8-inch mixing length between the fuel manifold and the flame holder was inadequate for proper vaporization of the low-vapor-pressure fuel. Unpublished data on a ram-jet burner using atomizing fuel nozzles show that with a mixing length of 36 inches there is no difference in combustion efficiency between these two fuels. Inasmuch as the burner-inlet temperature of the ram jet was only 570° F, while that of the tail-pipe burner was usually between 1000° and 1300° F, it is possible that an increase in mixing length alone would eliminate the difference in combustion efficiency without recourse to atomizing fuel nozzles.

The lower combustion efficiency of the 1.0-pound vapor-pressure fuel results in lower tail-pipe temperature (fig. 5) because of the fixed exhaust-nozzle area. To satisfy flow continuity, the gases then pass through the nozzle at a lower total pressure (fig. 6). The lower tail-pipe pressure and temperature are reflected upstream of the flame holder, giving lower pressure (fig. 7) and temperature (fig. 8) in the tail cone, at the burner inlet. The discrepancy in the trend of the 20,000-foot data is again due to the difference in the engine-inlet temperature previously mentioned. Because the engine was effectively operating at a lower engine speed for the low-vapor-pressure-fuel data at 20,000 feet, the pumping ability of the engine was less. Therefore the ratio of turbine-outlet pressure to compressor-inlet pressure and the ratio of turbine-outlet temperature to compressor-inlet temperature are

both lower. These lower ratios result in lower tail-cone and tail-pipe pressures but in a higher tail-cone temperature (fig. 8) because of the higher compressor-inlet temperature. From considerations of continuity the tail-pipe temperature (fig. 5) for the low-vapor-pressure fuel was lower than might have been expected.

In an axial-flow turbojet engine the air flow is not appreciably affected by changes in pressure in the engine downstream of the compressor. The lower tail-pipe pressure obtained with the 1.0-pound vapor-pressure fuel therefore resulted in lower thrust (fig. 9) and consequently in higher specific fuel consumption (fig. 10). The specific fuel consumption is based on the total fuel flow of the engine combustors and tail-pipe burner together.

It should be noted that if the exhaust nozzle had been of the infinitely variable type instead of two-position, it may have been possible to reduce the nozzle area slightly for the low-vapor-pressure-fuel runs so as to obtain the same tail-pipe conditions as those obtained with the MIL-F-5624 fuel. The major effect of the loss in combustion efficiency of the low-vapor-pressure fuel would then have been merely an increased fuel flow.

The maximum altitude at which the tail-pipe burner would operate was only slightly affected by the change in fuel volatility (fig. 11). In this figure, the abscissa is based on tail-pipe fuel flow as before but is based on the total air flow through the engine instead of on unburned air in the turbine-discharge gases. This change in abscissa was necessary because no measurement of engine fuel flow was recorded at the instant of the tail-pipe-burner blow-out. The MIL-F-5624 fuel operated at a slightly greater maximum altitude over most of the range of burner fuel-air ratio. It also operated satisfactorily at a somewhat leaner ratio before blowing out and reached the limiting turbine-discharge temperature at a lower fuel-air ratio than the low-vapor-pressure fuel.

## SUMMARY OF RESULTS

The results of a tail-pipe-burner performance investigation at a simulated flight Mach number of 0.6 and altitudes ranging from 20,000 feet to 45,000 feet with two fuels having Reid vapor pressures of 1.0 and 6.3 pounds per square inch, respectively, may be summarized as follows:

1. With the tail-pipe-burner configuration used in this investigation, having a mixing length of only 8 inches between the fuel manifold and the flame holder, the low-vapor-pressure fuel gave lower combustion efficiency in the tail-pipe burner.

2. Because the exhaust-nozzle area was fixed, the lower combustion efficiency of the low-vapor-pressure fuel caused lower tail-pipe temperatures and total pressures, resulting in lower thrust and higher specific fuel consumption at a given tail-pipe fuel-air ratio.

3. The maximum altitude at which the tail-pipe burner would operate was essentially unaffected by the change in fuel volatility.

Lewis Flight Propulsion Laboratory,
     National Advisory Committee for Aeronautics,
         Cleveland, Ohio.

## REFERENCES

1. Meyer, Carl L.: Altitude-Wind-Tunnel Investigation of AN-F-58 Fuel in Experimental Version of J47 Turbojet Engine. NACA RM E8L13, 1949.

2. Wilsted, H. D. and Armstrong, J. C.: Comparison of Performance of AN-F-58 and AN-F-32 Fuels in J33-A-23 Turbojet Engine. NACA RM E8K24, 1949.

3. Wilsted, H. D. and Armstrong, J. C.: Effect of Fuel Volatility on Altitude Starting Limits of a Turbojet Engine. NACA RM E50G10, 1950.

TABLE I - FUEL ANALYSES

| | Specification MIL-F-5624 | Analysis | |
|---|---|---|---|
| | | MIL-F-5624[a] | 1.0-pound Reid vapor pressure fuel[b] |
| ASTM distillation, °F: | | | |
| Initial boiling point | ------------- | 118 | 181 |
| Percent evaporated | | | |
| 5 | ------------- | 130 | 242 |
| 10 | ------------- | 143 | 271 |
| 20 | ------------- | 160 | 300 |
| 30 | ------------- | 177 | 319 |
| 40 | ------------- | 196 | 332 |
| 50 | ------------- | 217 | 351 |
| 60 | ------------- | 250 | 365 |
| 70 | ------------- | 334 | 381 |
| 80 | ------------- | 393 | 403 |
| 90 | 400 (min.) | 431 | 441 |
| 95 | ------------- | 453 | 470 |
| Final boiling point (max.) | 600 | 485 | 508 |
| Residue (max. percent) | 1.5 | 1.2 | 1.0 |
| Loss (max. percent) | 1.5 | 1.3 | 0.5 |
| Freezing point, °F (max.) | -76 | --- | below -76 |
| Aromatics (max. percent by volume): | | | |
| ASTM D-875-46T | 25 | --- | --- |
| Silica Gel | ------------- | --- | 5.72 |
| Bromine number (max.) | 30.0 | --- | 1.4 |
| Reid vapor pressure (lb/sq in.) | 5 to 7 | 6.3 | 1.0 |
| Hydrogen-carbon ratio | ------------- | 0.173 | 0.170 |
| Heat of combustion (min. Btu/lb) | 18,400 | 18,811 | 18,691 |
| Specific gravity | 0.728 to 0.802 | 0.736 | 0.780 |
| Accelerated gum (max. mg/100 ml) | 20.0 | --- | 5 |
| Air jet residue (max. mg/100 ml) | 10.0 | --- | 2 |
| Sulfur (max. percent by weight) | 0.50 | --- | --- |

[a]NACA Fuel numbers 50-213 and 50-214.
[b]NACA fuel number 50-197.
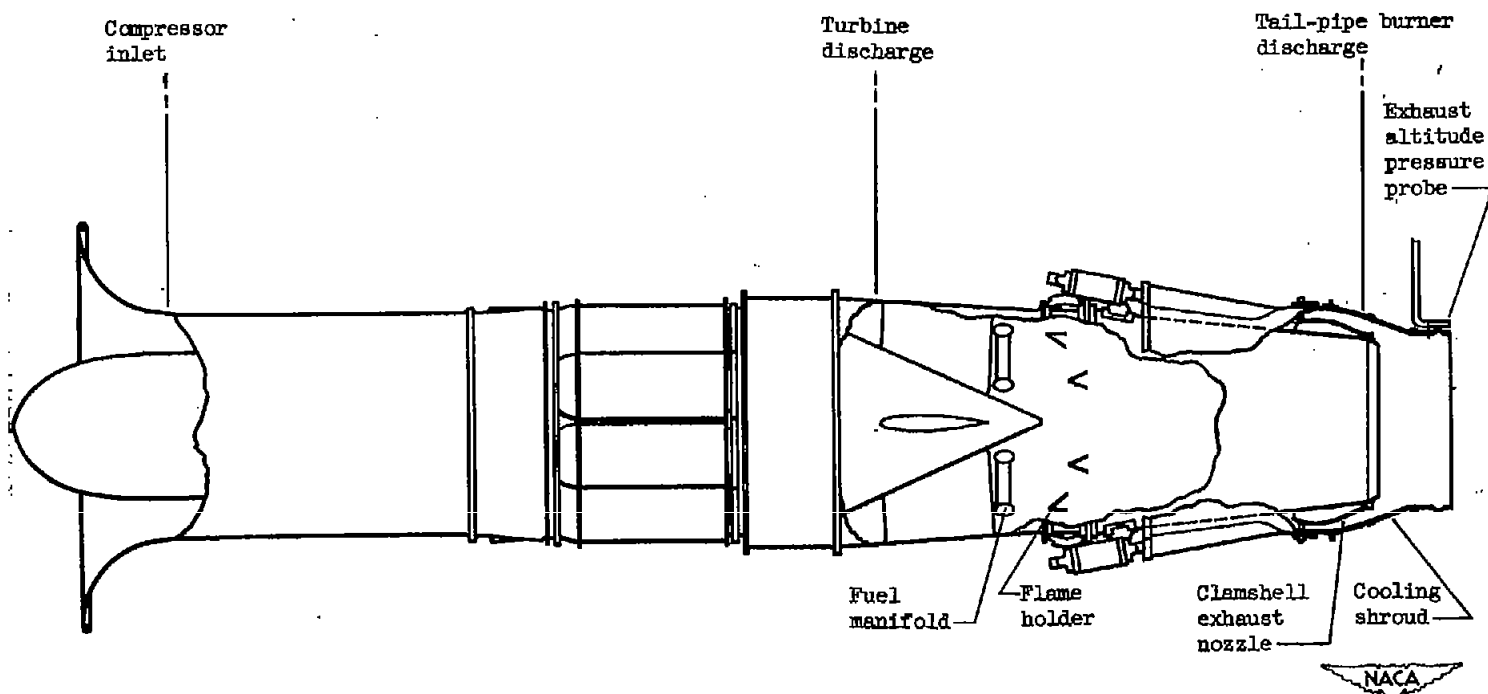
Figure 1. - Schematic cross-sectional view of engine and tail-pipe burner showing instrumentation stations and burner components.

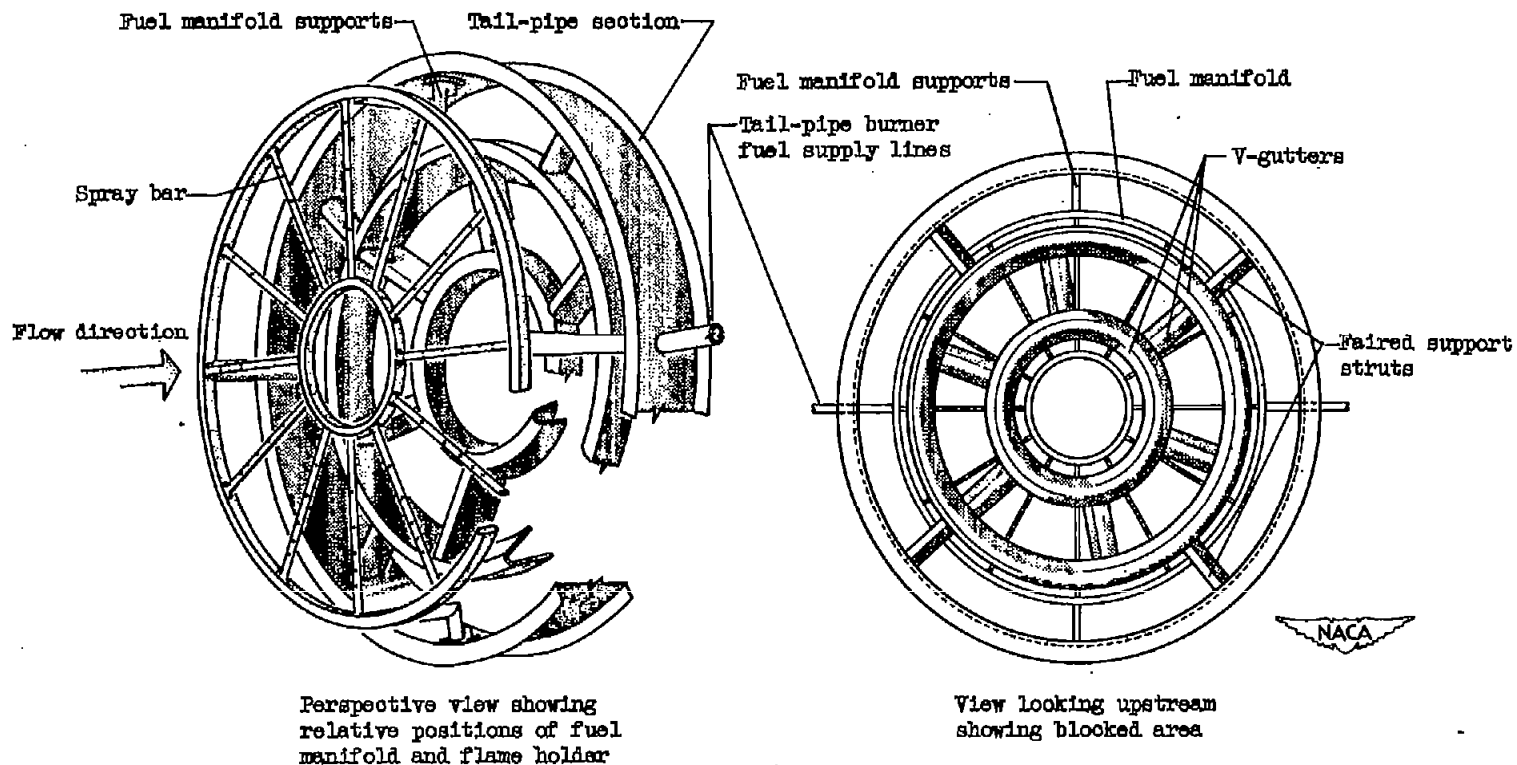Fuel manifold supports

Tail-pipe section

Fuel manifold supports

Fuel manifold

Tail-pipe burner fuel supply lines

Spray bar

V-gutters

Flow direction

Faired support struts

Perspective view showing relative positions of fuel manifold and flame holder

View looking upstream showing blocked area

Figure 2. - Detailed sketch of fuel manifold and flame-holder configuration.
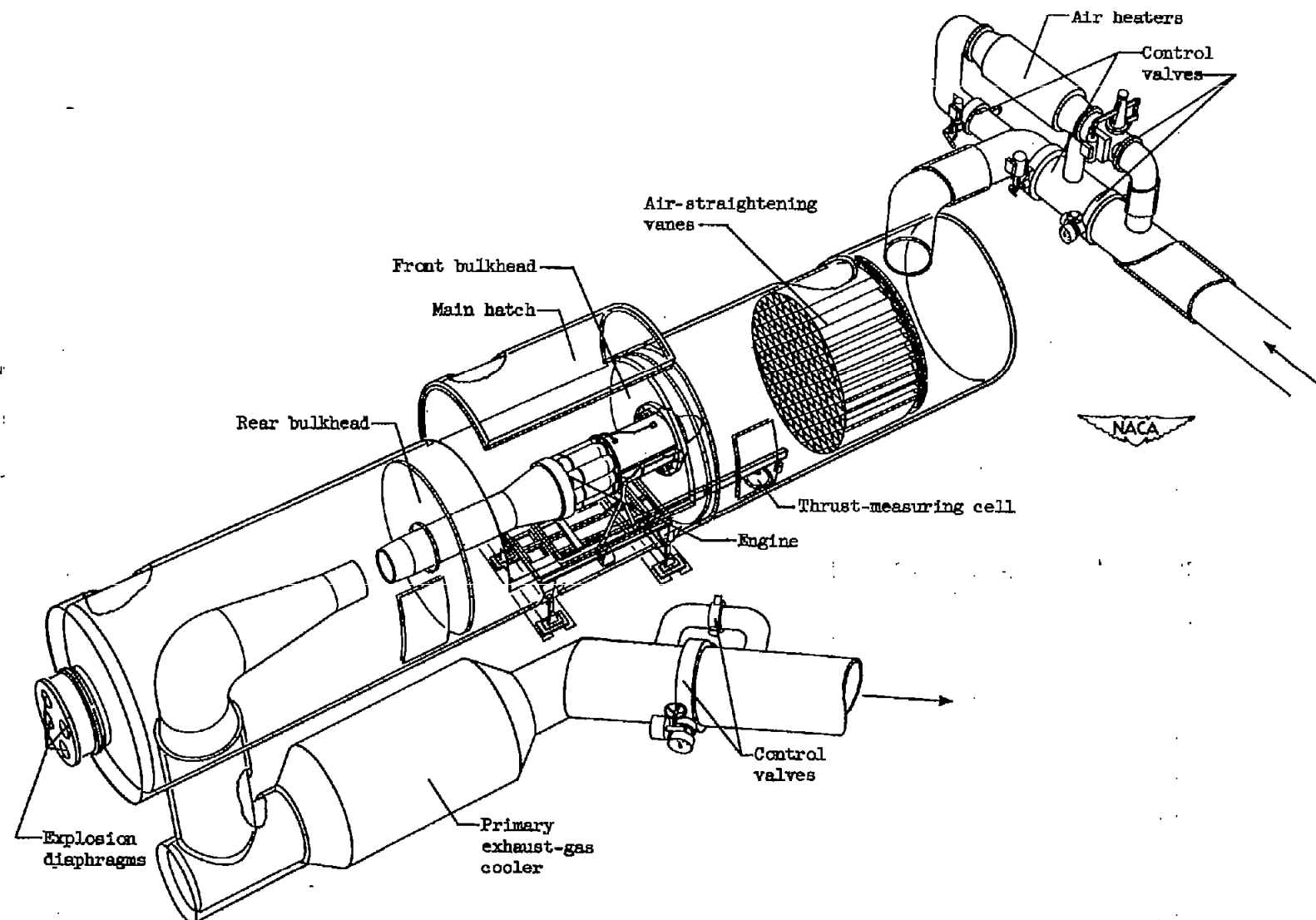
Figure 3. - Sketch of altitude chamber showing engine installed in test section.
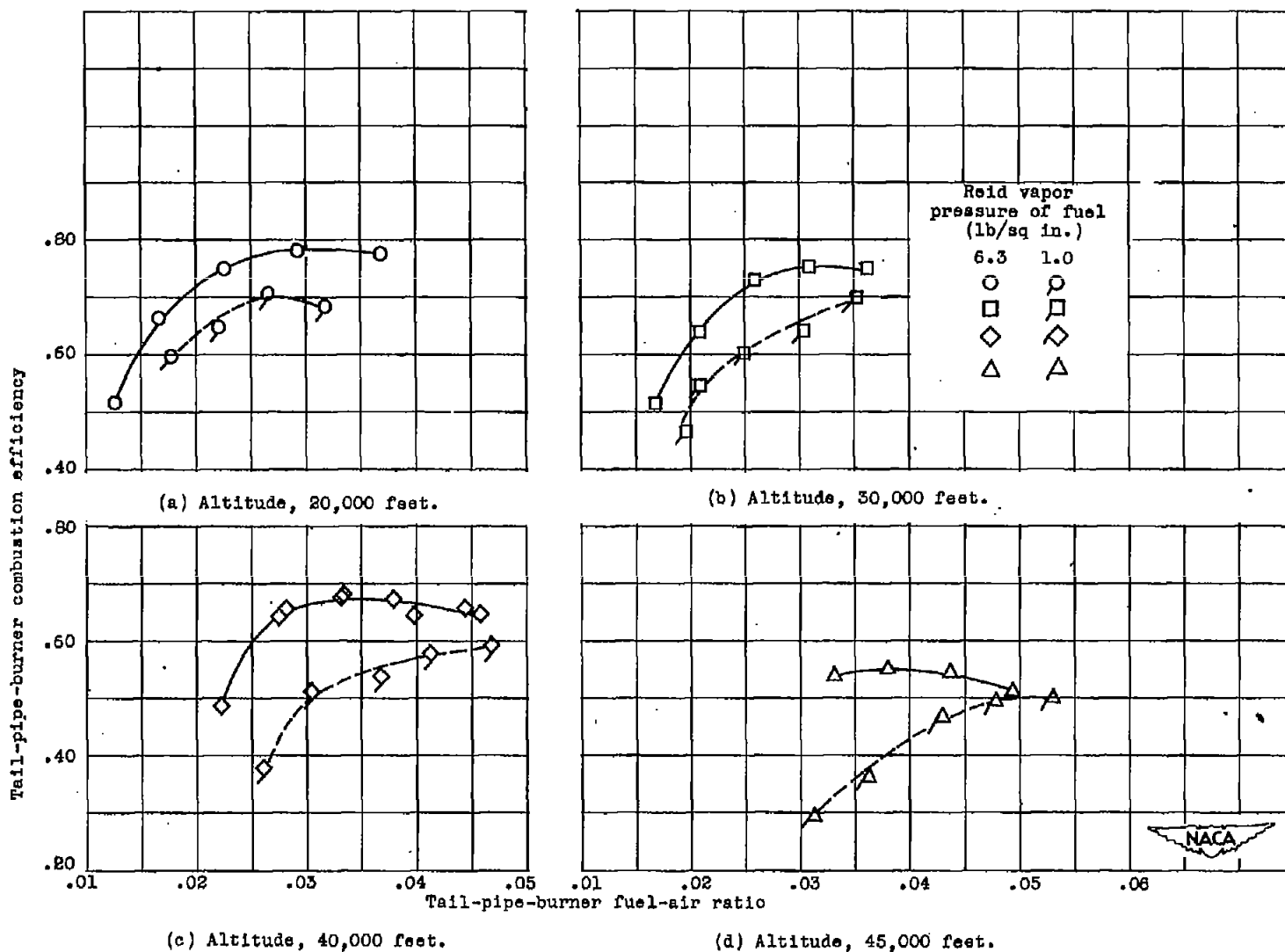
Figure 4. - Effect of tail-pipe-burner fuel volatility on burner combustion efficiency for axial-flow turbojet engine. Flight Mach number, 0.6; rated engine speed.
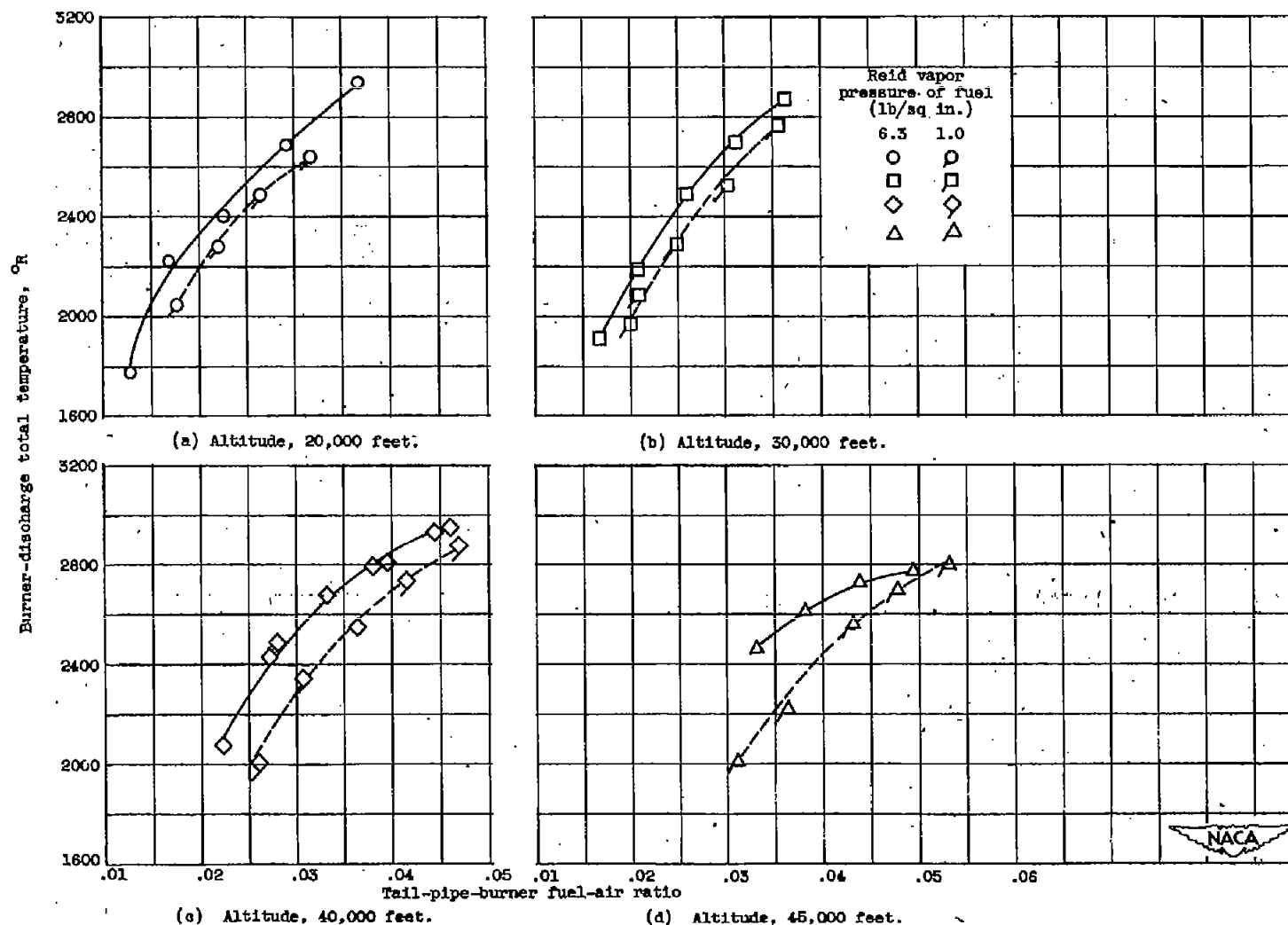
Figure 5. - Effect of tail-pipe-burner fuel volatility on burner-discharge total temperature for axial-flow turbojet engine. Flight Mach number, 0.6; rated engine speed.
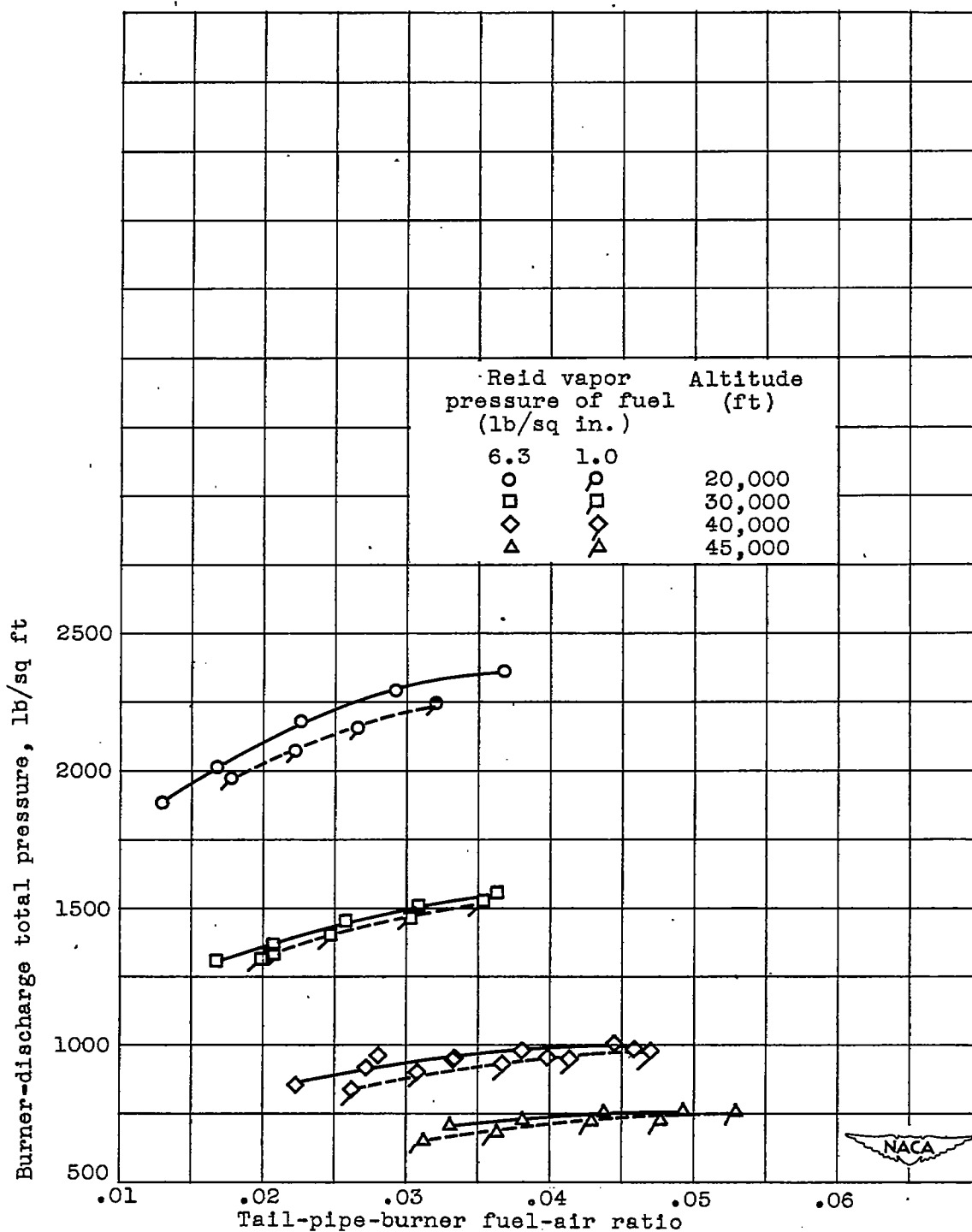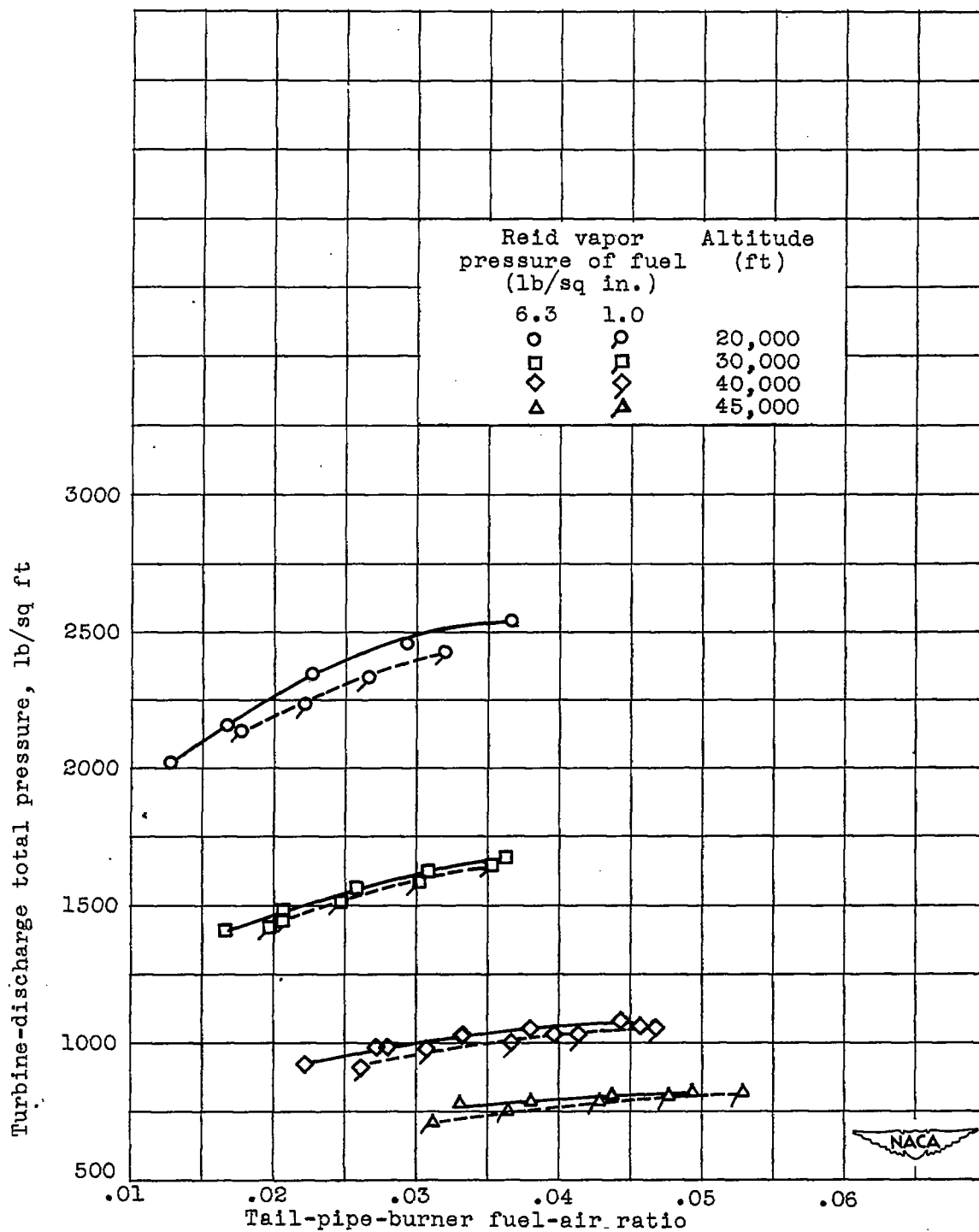
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Figure 6. - Effect of tail-pipe-burner fuel volatility on burner-discharge total pressure for axial-flow turbojet engine. Flight Mach number, 0.6; rated engine speed.

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Figure 7. - Effect of tail-pipe-burner fuel volatility on
turbine-discharge total pressure for axial-flow turbo-
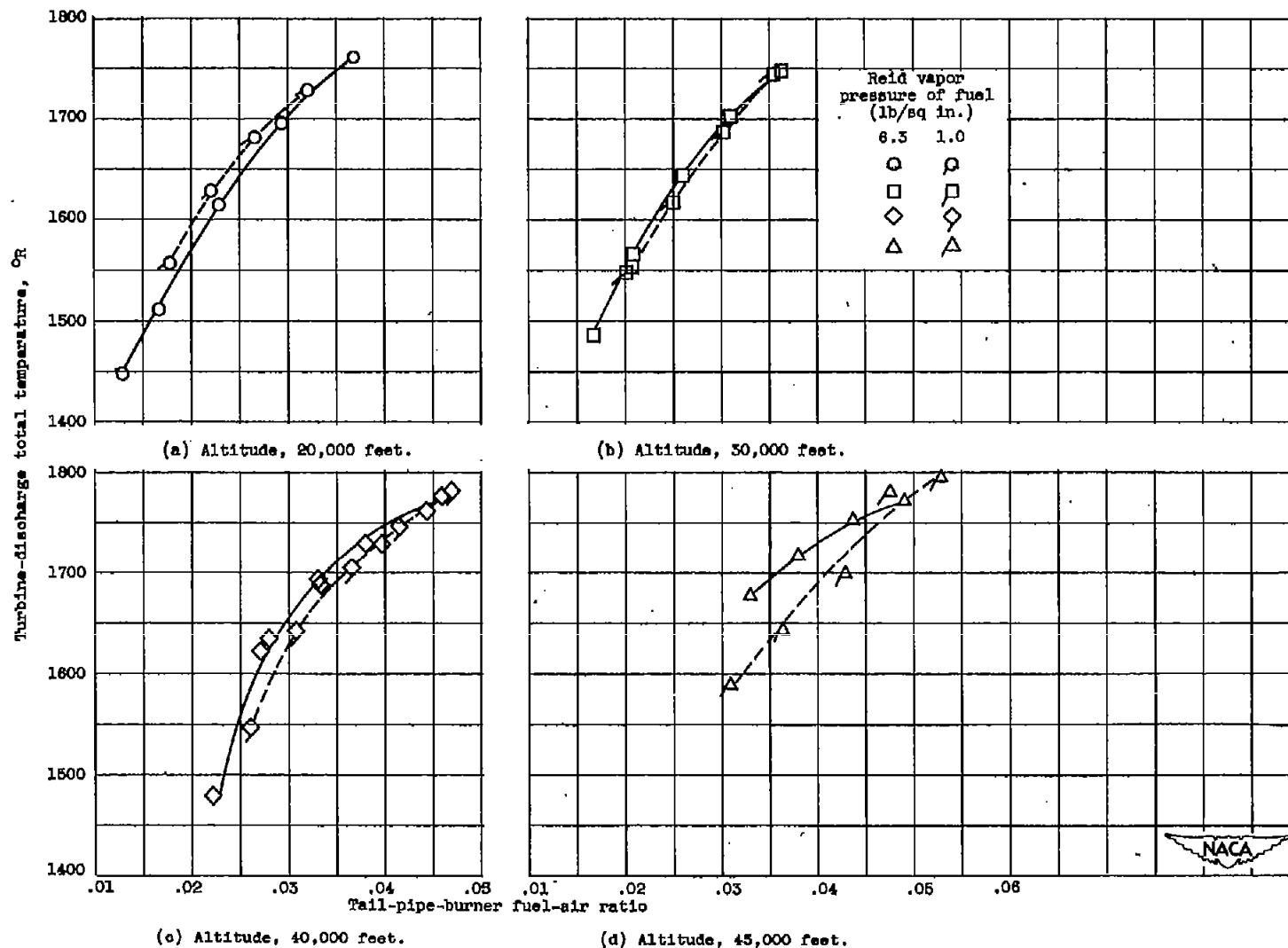jet engine.  Flight Mach number, 0.6; rated engine speed.

Reid vapor
pressure of fuel
(lb/sq in.)

6.3    1.0

(a) Altitude, 20,000 feet.

(b) Altitude, 50,000 feet.

(c) Altitude, 40,000 feet.

(d) Altitude, 45,000 feet.

Turbine-discharge total temperature, $^\circ R$

Tail-pipe-burner fuel-air ratio

Figure 8. - Effect of tail-pipe-burner fuel volatility on turbine-discharge total temperature
for axial-flow turbojet engine. Flight Mach number, 0.8; rated engine speed.
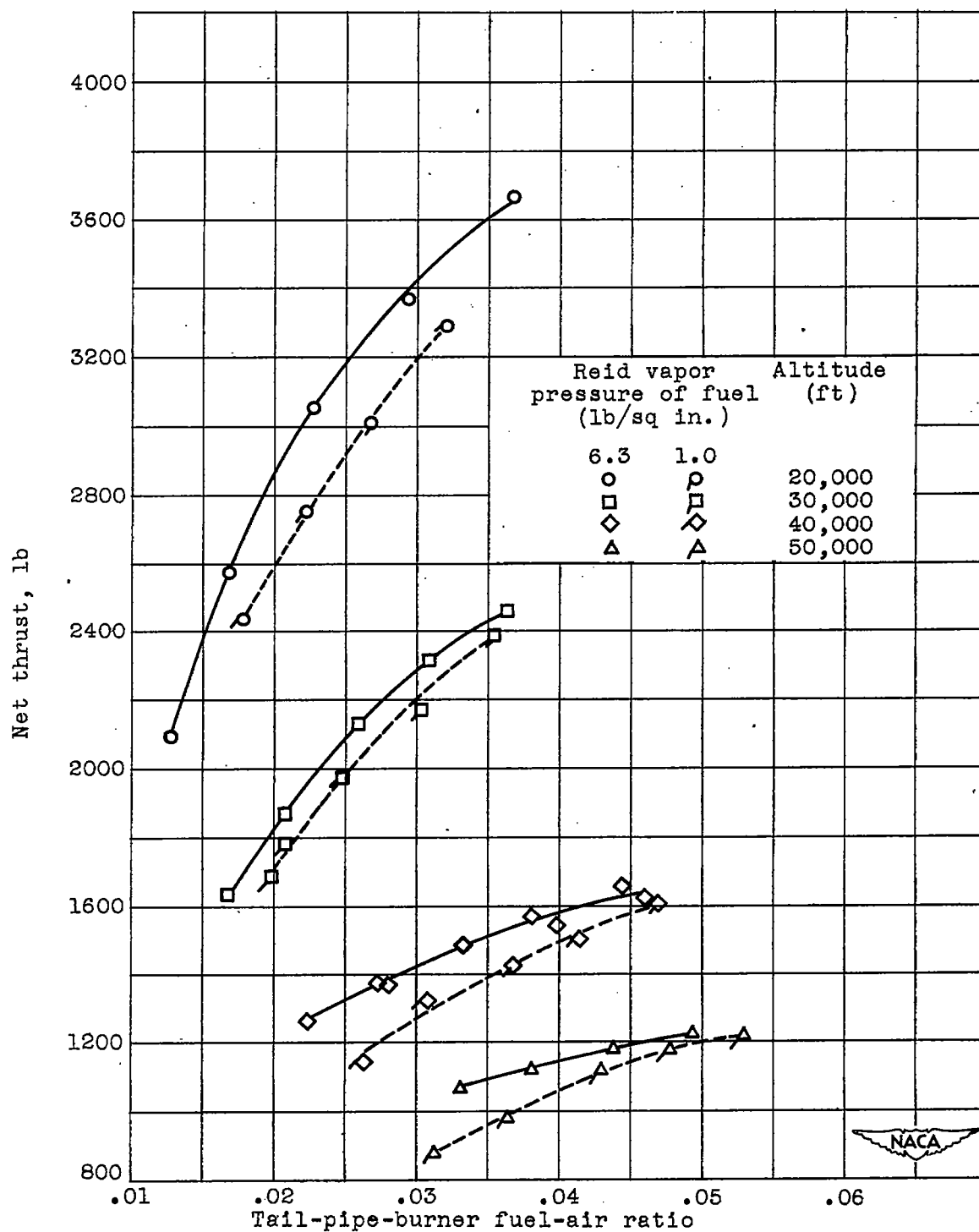
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Figure 9. - Effect of tail-pipe-burner fuel volatility on
net thrust for axial-flow turbojet engine. Flight Mach
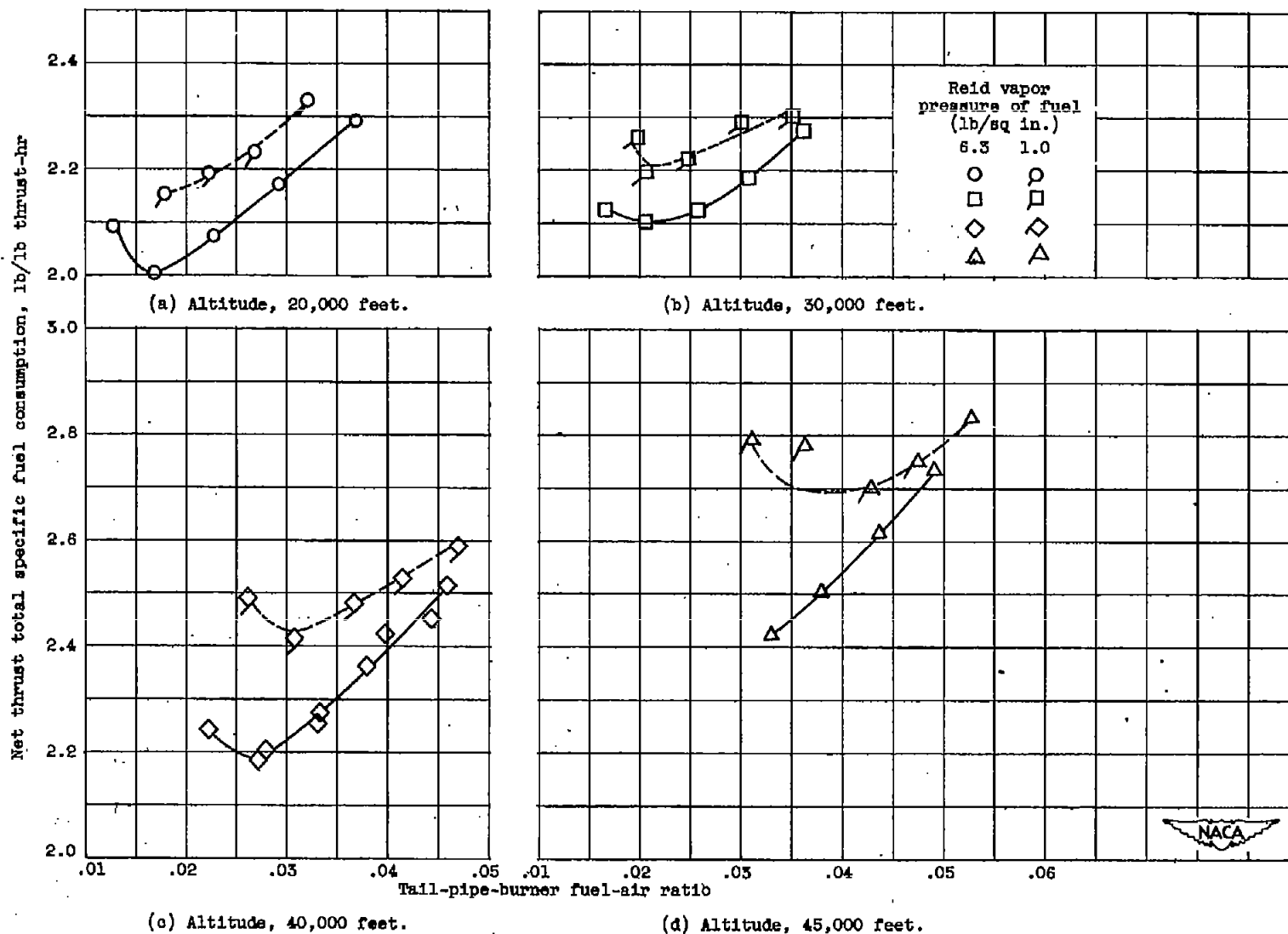number, 0.6; rated engine speed.

Figure 10. - Effect of tail-pipe-burner fuel volatility on net-thrust total specific fuel consumption for axial-flow turbojet engine. Flight Mach number, 0.6; rated engine speed.
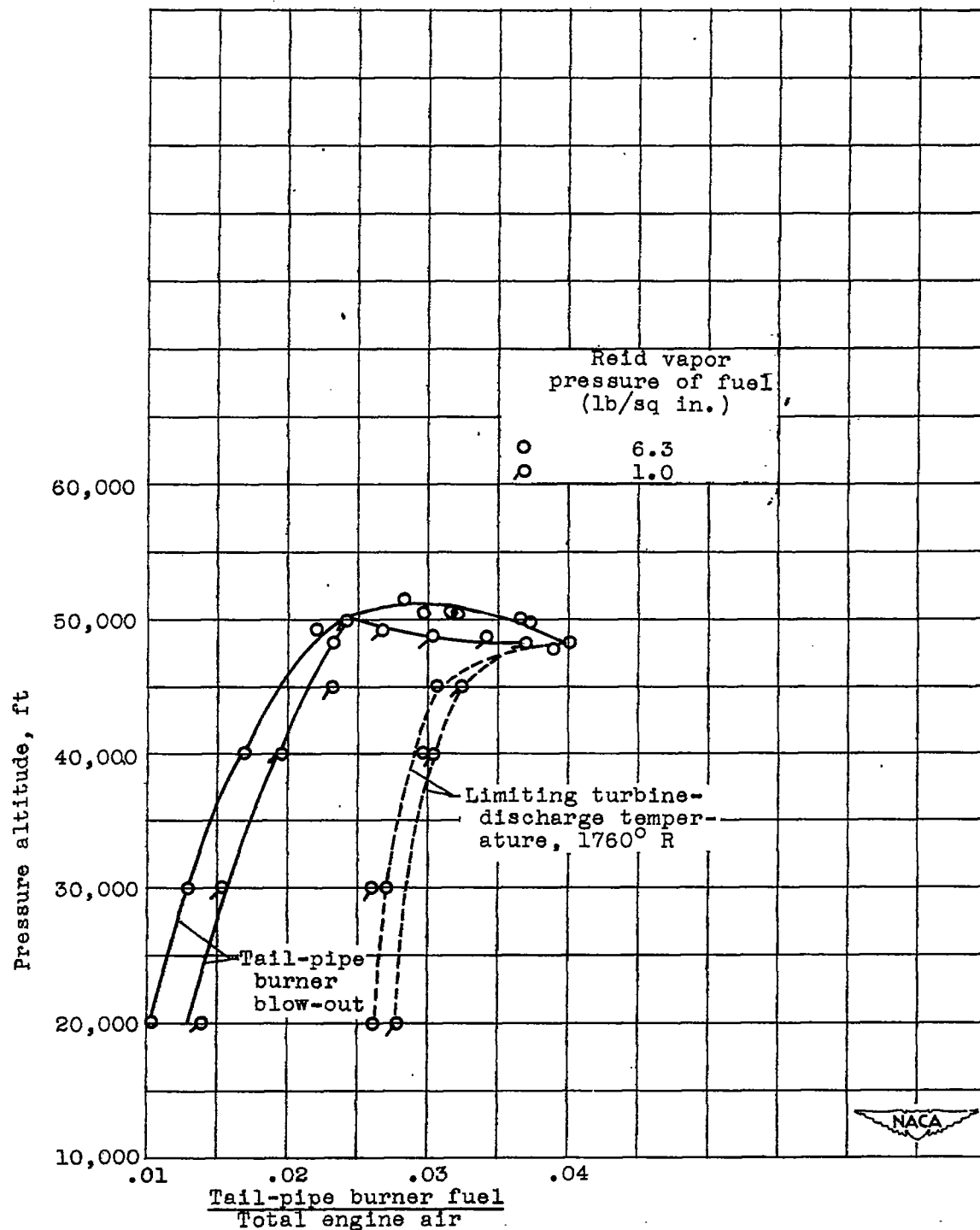
Figure 11. - Effect of fuel volatility on range of altitude
operation of tail-pipe burner on axial-flow turbojet
engine. Flight Mach number, 0.6; rated engine speed.